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A Longitudinal Study of Engineering Student Performance and Retention. III. Gender Differences in Student Performance and Attitudes

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ABSTRACT

In a continuing study under way at North Carolina State University, a cohort of students took five chemical engineering courses taught by the same instructor in five consecutive semesters. This report examines gender differences in the students' academic performance, persistence in chemical engineering, and attitudes toward their education and themselves. The women in the study on average entered chemical engineering with credentials equal to or better than those of the men, but exhibited erosion relative to the men in both academic performance and confidence as they progressed through the curriculum. Possible causes of the observed disparities are suggested and remedial measures are proposed.

A LONGITUDINAL STUDY OF ENGINEERING STUDENT PERFORMANCE AND RETENTION

A longitudinal study of chemical engineering students has been under way at North Carolina State University since the fall of 1990. Previous articles summarized correlates of success and failure in the introductory chemical engineering course[1] and compared outcomes for students from rural and small-town backgrounds with outcomes for students from urban and suburban backgrounds.[2] This paper summarizes gender differences in the students' academic performance, persistence in chemical engineering, and attitudes toward their education and themselves. A more complete report of the data and results may be obtained from the ERIC Document Reproduction Service.[3]

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I. WOMEN IN ENGINEERING: FALLING INTO THE GENDER GAP

The percentage of women enrolled in engineering curricula was almost negligible for the first seven decades of this century, rose in the 1970s and early 1980s, and then leveled off, with the actual number enrolled declining after 1986.[4] In 1992, women accounted for 15.0% of B.S. degrees, 14.8% of M.S. degrees, and 9.7% of Ph.D. degrees in engineering. The gender gap in the engineering profession is even more dramatic: women make up roughly 50% of the general population and 44% of the United States work force, but as of 1988 they represented only 4% of practicing engineers.[5]

For a variety of practical and moral reasons, steps must be taken to attract and retain more women in engineering curricula.[6] The obstacles to doing so are formidable, however. From an early age, women are told—subtly or overtly—that science and mathematics are not for them. Some get this message at home, most get it at school from classmates and occasionally from teachers, and many accept it. Boys, for example, are likely to ascribe problems with mathematics to the difficulty of the subject while girls are more likely to attribute failure to their lack of ability.[7,8]

Books and articles published in the 1970s and early 1980s suggested that males are innately superior in certain mathematical reasoning and visual-spatial abilities.[9–11] These writings, which continue to receive widespread publicity, may have discouraged many females from even thinking about entering scientific fields.[4] More recent studies have shown that some of the alleged ability differences disappear under more careful analysis, others are attributable to gender bias in standard aptitude and achievement tests, and still others result from differences in experience.[4,12–14] More disturbing than these questionable ability differences, however, are commonly observed differences in self-confidence. In elementary school, for example, boys and girls report equal confidence in mathematical abilities but by high school boys are far more confident.[15, 16] Similar patterns are found in science.[17]

The negative impression that many women have of their aptitude for technical subjects is heightened by the traditional instructional mode in college science and engineering courses, which stresses individual work and competitive grading. Tobias[18] suggests that “what may act as a spur to individual achievement among men is a significant deterrent for women.” Women in engineering curricula often report negative experiences[19] and even women who persist in technical curricula through graduation show marked declines in self-confidence and career aspirations.[20, 21]

Suggestions have been made that the difficulties encountered by women in technical curricula might be lessened by creating an academic environment that encourages and rewards the “cooperative behavior that is often necessary in scientific investigation,”[13] and positive results have been reported for women working in collaborative teams.[22] Cooperative learning was incorporated in the longitudinal study with these observations (among others) in mind.

The goal of this paper is to examine differences in performance and attitudes of the men and women in the study. In particular, we wish to investigate the extent to which the women in the experimental cohort exhibited (or failed to exhibit) the erosion of performance and confidence observed in the studies cited above, and to determine the degree to which the responses of the men and women to cooperative learning match previously observed patterns. Future work will extend the analysis to a comparison group of students who go through the chemical engineering curriculum as traditionally taught, enabling the impact of the experimental instructional methods on the students’ performance and confidence levels to be assessed.

II. DATA AND STATISTICAL ANALYSIS

Tables 1–12 report data for 87 men and 34 women who enrolled in the introductory chemical engineering course (CHE 205 – Chemical Process Principles) in the Fall 1990 semester. The responses shown for each item almost always fall short of these totals, either because students failed to respond to particular questionnaire items or because they dropped out of the experimental course sequence at some point. In several instances there are minor discrepancies between numbers in the tables and analogous numbers in an earlier report,[3] reflecting corrections made when this paper was written. None of the conclusions stated in the report were affected by the corrections. All reported levels of significance are derived from two-tailed Fisher's exact tests unless otherwise noted. "Statistically significant" signifies p<.1; statistically significant *p* values are marked in tables by asterisks. Additional details about the statistical methodology used in the study are given by Felder *et al*.[1, 2]

III. PRE-ENGINEERING DATA

A. Ethnicity and Family Background

Table 1 summarizes data on ethnicity, home communities, and parental educational levels of the students in the experimental cohort.

Table 1. Ethnicity, home, and parents

	Men	Women	p
Ethnic background	(N=86)	(N=34)	
African-American	7%	3%	
Caucasian	85%	76%	.14
Asian-American	2%	12%	
Other	6%	9%	
Home community	(N=86)	(N=34)	
Rural	15%	12%	
Small town	35%	24%	.19
Suburban	37%	35%	
Urban	13%	29%	
Father's highest education level	(N=79)	(N=31)	
Advanced degree	22%	29%	
Bachelor's degree	35%	55%	.04*
Attended college	15%	10%	
Never attended college	28%	6%	
Mother's highest education level	(N=78)	(N=30)	
Advanced degree	13%	27%	
Bachelor's degree	35%	37%	.23
Attended college	21%	20%	
Never attended college	32%	17%	
Parents trained in science	(N=47)	(N=15)	
Both	21%	33%	
Mother	4%	7%	.67
Father	43%	33%	
Neither	32%	27%	
Mother's employment history	(N=48)	(N=15)	
Had an outside job	46%	73%	
Student	4%	0%	.21
Stayed at home	50%	27%	

The ethnic backgrounds of the men and women were fairly similar, with the most notable difference being a higher percentage of women coming from Asian-American backgrounds. The men were more likely than the women to have attended high school in rural and small-town communities. The parents of the women were more highly educated than those of the men. Much higher percentages of both the women's fathers and mothers had college degrees, and over twice as many of the women's mothers had advanced degrees. More than four times as many men as women had fathers who never attended college, and nearly twice as many men had mothers who never attended college. Roughly equal percentages of women and men had fathers with training in science or technology, but notably more women had mothers with such training. A much higher percentage of women had mothers who worked outside the home.

A previous article showed that students in this study with urban and suburban backgrounds consistently outperformed students with rural and small-town backgrounds,[2] and parental educational levels have been shown to correlate with academic success.[23] Since relatively more men than women in the study came from rural/small-town homes and the women's parents were more highly educated, a reasonable (but incorrect) prediction based on the results in this section would be that the women should be more successful in chemical engineering.

B. Learning and Study Strategies Inventory

Toward the beginning of the first engineering course the students completed the *Learning and Study Strategies Inventory* (LASSI), an instrument that assesses students' test-taking skills and strategies, motivation to learn, and anxiety levels. As a rule, the lower the score on any of the 10 inventory scales, the more likely the student is to have academic problems related to the characteristic measured by that scale.

The women scored higher than or roughly the same as the men on all but the anxiety scale. They scored significantly higher on items relating to general attitudes toward learning (importance of school, clarity of educational goals), motivation to study (keeping up-to-date in assignments, maintaining interest in classes), and use of study aids (highlighting main points in texts, doing practice exercises). The women scored lower than the men on the anxiety scale, signifying a higher anxiety level, which could work to their advantage or detriment in terms of academic performance. One might again infer that on average the women entered the chemical engineering curriculum better equipped than the men to meet its academic challenges. More details about the LASSI profiles and their implications are given by Felder *et al*.[3]

C. Pre-College and First College Year Performance

Table 2 shows selected pre-college academic credentials of the students. There were no significant gender differences in SAT scores (although it is noteworthy that the women had a slightly higher average SAT mathematics score) or in advanced placement credit for required freshman calculus, chemistry, or physics courses.

Table 2. Pre-college academic performance.

	Men	Women	p
Admissions criteria	(N=71)	(N=30)	
SATM	625	637	.50*
SATV	523	522	.97*
Percentage receiving AP credits in courses	(N=82)	(N=34)	
MA141	20%	18%	1.00
MA241	5%	0%	.32
CR101	4%	3%	1.00
CR107	4%	3%	1.00
PY205	2%	0%	1.00

**t-test*

Table 3 shows first-year grade-point averages (AP credit not included) and average grades in selected first-year courses (A=4.0, AP credit=5.0). The women had a slightly higher overall grade point average than the men and significantly outperformed the men in the English course. There were no statistically significant performance differences in the mathematics and science courses.

Table 3. First-year academic performance.

	Men (N)	Women (N)	p
First year course grades[a]			
Overall GPA	3.21 (70)	3.31 (30)	.41[b]
MA141	3.31 (72)	3.29 (31)	.95[c]
MA241	3.01 (75)	2.97 (31)	.41[c]
CH101	3.41 (74)	3.58 (31)	.62[c]
CH107	3.31 (74)	3.26 (31)	.45[c]
PY205	2.82 (73)	2.55 (29)	.25[c]
ENG111	3.84 (70)	4.45 (29)	.02[c]*

[a]A=4.0, AP credit=5.0
[b]t-test
[c]Wilcoxon's rank-sum test

D. Implications of Pre-Engineering Data

Considerable social pressure is brought to bear on females from an early age not to pursue technical careers. One might therefore expect that women who overcome these pressures and enroll in engineering would be well equipped with both the motivation and the aptitude to succeed.

This expectation was borne out for the women in this study, whose backgrounds and pre-engineering academic credentials marked them as more likely to succeed than the men. Their parents were on average more highly educated and had received more training in science or technology. They scored equally well or better than the men on pre-college admission tests. According to the LASSI, they were more highly motivated to study, had greater powers of concentration, were better able to extract the main ideas from readings, and made better use of study aids.

Nevertheless, the women did not do significantly better than the men in their first year of college except in non-technical courses, suggesting the existence of factors working against them. We defer discussion of what these factors might be until outcomes from engineering courses have been summarized.

IV. PERFORMANCE IN CHEMICAL ENGINEERING

A. Grades in Chemical Engineering Courses

The five courses listed below constituted the experimental sequence. Also shown are the number of men and women in the experimental cohort who enrolled in each course.

CHE 205–Chemical Process Principles (M–87, W–34).
CHE 225–Chemical Process Systems (M–53, W–18).
CHE 311–Transport Processes I (M–50, W–17).
CHE 312–Transport Processes II (M–45, W–16).
CHE 446–Chemical Reactor Design and Analysis (M–40, W–15).

The courses were taught in successive semesters, beginning with CHE 205 in the first semester of the students' sophomore year (Fall 1990). The percentage of women enrolled remained relatively constant in the 25–28% range. Table 4 summarizes student performance in each of the five courses. The men generally did better, with substantial differences occurring in the percentages of men and women earning A's in CHE 225 and CHE 312.

Table 4. Performance in experimental courses.

	205			225			311		
	M	W	p	M	W	p	M	W	p
N	87	34		53	18		50	17	
Letter grade A B C D F/Drop[a]	 25% 33% 9% 8% 24%	 18% 32% 18% 9% 24%	.71	 45% 38% 11% 2% 4%	 22% 44% 28% 6% 0%	.20	 30% 34% 26% 6% 4%	 24% 24% 41% 6% 6%	.77
Percentage receiving A's	25%	18%	.48	45%	22%	.10*	30%	24%	.76
Percentage passing[b]	68%	68%	1.00	94%	94%	1.00	90%	88%	1.00
Average grade (A=4.0)	2.28	2.12	.48[c]	3.19	2.83	.07[c]	2.80	2.53	.34[c]

	312			446		
	M	W	p	M	W	p
N	45	16		40	15	
Letter grade A B C D F/Drop[a]	 51% 31% 18% 0% 0%	 19% 56% 25% 0% 0%	.08*	 32% 52% 15% 0% 0%	 27% 33% 40% 0% 0%	.14
Percentage receiving A's	51%	19%	.04*	32%	27%	.75
Percentage passing[b]	100%	100%		100%	100%	
Average grade (A=4.0)	3.33	2.94	.06[c*]	3.18	2.87	.18[c]

[a] Students who dropped any course after 205 were not counted in the statistics for that course.
[b] "Passing" refers to receiving a grade of C or better, which is required to advance in the curriculum.
[c] Wilcoxon's rank-sum test

Grades obtained by the students in chemical engineering courses taught by other instructors were also averaged.[3] Although none of the gender differences was statistically significant, notably higher percentages of the men earned A's in two of the courses, paralleling the results in the experimental sequence.

B. Status of the Students after Their Second and Fourth Years of College

Table 5 shows the academic status of the students at the end of the first year of the study (the second year of college) and Table 6 provides similar data for the end of the third year (the fourth year of college). Students still enrolled in chemical engineering and not on academic suspension were classified as having been "retained" in the curriculum, whether or not they were still in the experimental course sequence.

There were some noteworthy differences in academic status—albeit no statistically significant ones—between the men and women after their sophomore year of college (Table 5). A slightly higher percentage of men than of women failed one of the experimental courses and remained in chemical engineering, while a substantially higher percentage of women transferred out of chemical engineering after failing a course. A higher percentage of women joined the coop (work-study) program, although the percentages would later converge. Equal percentages of men and women dropped out of school or went on academic suspension. Of those in the experimental cohort who had intended to pursue chemical engineering degrees when they began CHE 205, a higher percentage of the men was still enrolled.

Table 5. Status in the CHE curriculum after second year of college

	Men	Women	p
Status[a]	(N=87)	(N=34)	
A	57%	50%	
B	21%	18%	
C	3%	9%	
D	1%	0%	.34
E	2%	12%	
F	3%	3%	
G	11%	9%	
Retention[b]	(N=77)	(N=31)	
Retained	92%	84%	.29
Not retained	8%	16%	

[a] A = In sequence (passed 205 and 225)
B = Behind sequence (failed 205 or 225)
C = Joined the coop program
D = Transferred out of CHE in good standing
E = Transferred out of CHE after failing 205
F = Dropped out of school or suspended
G = Never was a CHE major

[b] Retained = Category A, B, or C
Not retained = Category D, E, or F

Table 6. Status in the CHE curriculum after fourth year of college

	Men	Women	p
Status[a]	(N=87)	(N=34)	
A	16%	18%	
B	11%	6%	
C	9%	12%	
D	6%	3%	.34
E	3%	12%	
F	10%	3%	
G	11%	9%	
H	35%	36%	
Retention[b]	(N=77)	(N=31)	
Retained	81%	77%	.79
Not retained	19%	23%	
Overall GPA	(N=81)	(N=33)	
	3.02	3.08	.69[c]
CHE GPA	(N=81)	(N=32)	
	2.64	2.55	.72[c]

[a] A = In sequence (passed 205 and 225)
B = Behind sequence (failed 205 or 225)
C = Joined the coop program
D = Transferred out of CHE in good standing
E = Transferred out of CHE after failing 205
F = Dropped out of school or suspended
G = Never was a CHE major

[b] Retained = Category A, B, or C
Not retained = Category D, E, or F

[c] t-test

After the fourth year of college (Table 6), essentially equal percentages of men and women had graduated in chemical engineering or had taken and passed all experimental courses but had not yet graduated. Men were nearly twice as likely as women to be behind sequence in chemical engineering. Women were more likely to have transferred out of chemical engineering in good standing and much more likely to have transferred out after failing a course. More than three times as many men as women had dropped out of school or were on academic suspension. At the end of the fourth year, the women had a slightly higher overall GPA than the men and the men had a small but nonsignificant advantage in chemical engineering GPA.

In summary, the men in the study consistently earned equal or higher grades in chemical engineering courses than did the women, and the percentage of men earning A's in several courses was significantly greater than the percentage of women doing so. Of the students who had intended to major in chemical engineering when they began the first course, the percentage of women who dropped out for any reason after the sophomore year was twice the percentage of men dropping out. The percentages dropping out by the end of the senior year were closer, with relatively more women transferring into other curricula and considerably more men dropping out of school or being suspended. Throughout the period of the study, men who failed a chemical engineering course were more likely than women to repeat the course and remain in the curriculum, while women who failed a course were more likely than the men to switch out of chemical engineering. These results are consistent with patterns described by Dweck and Repucci,[24] who observed that young men are more likely than young women to persist in the face of academic challenges, and by Astin,[23] who noted a greater tendency of women than men to drop out of engineering.

If one just considers retention statistics, there might seem to be little occasion for alarm in these results—after all, the four-year graduation rates and retention rates showed only minor gender differences. Recall, however, that the women in the study came into engineering with better predictors of success—higher levels of parental education, higher SAT scores, better study skills and strategies, etc.—and the instruction in the experimental courses had been designed to reduce or eliminate some of the factors purported to work against women in engineering, e.g. by stressing cooperation over competition. The women might consequently have been expected to outperform the men in engineering courses, but in fact the men did better, especially at the upper end of the grade spectrum. This result is surely cause for concern.

V. ATTITUDES AND SELF-ASSESSMENTS

A. Confidence Levels and Self-Expectations

As Table 7 shows, the women beginning their first engineering course (CHE 205) reported somewhat higher levels of anxiety than the men about both that course and about schoolwork in general. This result is consistent with that previously reported for the LASSI inventory, which also showed the women with higher anxiety levels. The men were significantly more positive about the quality of the academic preparation they had received for CHE 205. In their eighth semester of college, the men remaining in the experimental course sequence continued to be more confident about their academic preparation than the women, with 22% of the men and only 7% of the women rating their preparation for the senior design course as "excellent."

Table 7. Self-assessments of anxiety levels and academic preparation.

	Men	Women	p
Anxiety level about CHE 205	(N=85)	(N=34)	
Very anxious	28%	41%	
Somewhat anxious	53%	50%	.43
Slightly anxious	18%	9%	
Not at all anxious	1%	0%	
Anxiety level about schoolwork in general	(N=85)	(N=34)	
Very anxious	25%	41%	
Somewhat anxious	46%	44%	.21
Slightly anxious	26%	15%	
Not at all anxious	4%	0%	
Academic preparation for CHE 205	(N=84)	(N=34)	
Weak/Average	55%	76%	.04*
Strong	45%	24%	
Academic preparation for CHE 451	(N=49)	(N=15)	
Excellent	22%	7%	
Good	57%	67%	.68
Fair	10%	13%	
Poor	2%	0%	
Don't know	8%	13%	

In each questionnaire the students were asked to state the lowest final grade that would satisfy them in the course they were taking at the time. Table 8 summarizes the results. At the beginning of CHE 205 the women expressed slightly higher requirements than the men, with over twice the percentage of women than of men saying that they would require creative work beyond that required to earn an A. By the middle of that course (after the first test) both men and women had lowered their criteria for satisfaction, and the men's were now higher. The implication is that even at this early stage of the engineering curriculum the women were starting to have greater difficulty and/or to experience a greater loss of confidence. This trend continued as the men's satisfaction criteria continued to exceed the women's, with the difference reaching its maximum in the junior year (probably the most demanding year of the curriculum). In CHE 312, 64% of the men and only 19% of the women indicated that they would be satisfied with nothing less than an A. The decreased gender difference in the senior year is attributable more to a lowering of male expectations (perhaps a symptom of "senioritis") than to increased female expectations.

In two of the experimental courses, questions were asked that provide a more direct measure of expectations. In the CHE 205 preliminary questionnaire and the CHE 312 midterm questionnaire, students were asked to guess their final course grades. In CHE 205 almost all of the students guessed A or B, but the men were more likely to say A. In CHE 312 men were significantly more likely than women to say A or B, while far more women than men said C. As it happens, both men and women overpredicted their grades early in CHE 205, while in CHE 312 the men predicted their grades quite accurately and the women underpredicted theirs, suggesting that at least some of the women's lower expectations resulted from their underestimating their abilities.

Table 8. Requirements for satisfaction with grades.

	Men	Women	p
In 205 — Beginning	(N=85)	(N=34)	
Passing	1%	0%	
C or better	13%	6%	.57
B or better	54%	53%	
A	25%	26%	
Creative work beyond good grades	7%	15%	
In CHE 205 — Midterm	(N=79)	(N=30)	
D or better	3%	0%	
C or better	20%	33%	.60
B or better	49%	43%	
A	24%	23%	
Creative work beyond good grades	4%	0%	
In CHE 311 — Midterm	(N=48)	(N=15)	
B or below	46%	80%	.04*
A or better	54%	20%	
In CHE 312 — Midterm	(N~=44)	(N=16)	
B or below	36%	81%	.003*
A or better	64%	19%	
In CHE 446 — Midterm	(N=43)	(N=18)	
C or better	9%	6%	
B or better	30%	61%	.18
A	49%	28%	
Creative work beyond good grades	12%	6%	
In remaining senior CHE courses	(N=51)	(N=16)	
D or better	2%.	12%	
C or better	10%	12%	.52
B or better	53%	50%	
A	22%	19%	
Creative work beyond good grades	14%	6%	

B. Attributions of Success and Failure

In all of the questionnaires, the students were asked to guess what the most likely reason would be if they were to perform below their own expectations in the course (Table 9). The responses varied considerably from course to course, but some trends emerged. "Not working hard enough" was the most common response of both men and women in all courses, but it was by far the predominant male response and it was always given by higher percentages of men except at the beginning of CHE 205. Lack of ability was consistently chosen by a substantially higher percentage of women except at the beginning of CHE 205 (where the difference was slight), and women were more likely to cite personal problems in three of the five courses. In three out of four courses men were more likely to say that their poor performance would be due to unfair tests and/or grading, although very few such complaints were ever actually expressed.

The converse question was also posed, i.e., what the most likely reason would be if the students performed above their expectations in the course (Table 10). Hard work was cited by the highest percentages of both men and women, but men were consistently more likely to report their own ability as the most likely factor while in four of five courses women were more likely to cite help or support from someone else. These attribution patterns match those observed by Fennema and Leder,[25] who found that female mathematics students tend to attribute failure to themselves and success to help from others while male students tend to do the opposite. The data also show that the greater tendency of women to downrate their ability was much less pronounced at the beginning of CHE 205 than later in the curriculum, and may have even been slightly reversed at the beginning of CHE 205 (Table 9).

In short, the women in the study entered the engineering curriculum with greater anxiety and lower confidence in their preparation than did the men. They began the first course with higher expectations of themselves, but by the midpoint of the first chemical engineering course their expectations were lower than those of the men, and the disparity persisted throughout the curriculum. The women were more likely than the men to attribute poor performance to their own lack of ability and men were more likely to attribute it to a lack of hard work or being treated unfairly. Conversely, men were more likely than women to attribute success to their ability and women more likely than men to attribute it to outside help.

Table 9. Most likely reason if performance is below expectations.

	Men	**Women**	**p**
In CHE 205 (beginning)	(N=85)	(N=34)	
Lack ability	12%	9%	
Don't work hard enough	61%	71%	.87
Course too demanding	16%	12%	
Problems in personal life	11%	9%	
In CHE 311 (midterm)	(N=46)	(N=15)	
Lack ability	4%	13%	
Don't work hard enough	52%	33%	.29
Course too demanding	26%	20%	
Tests/grading unfair	2%	0%	
Problems in personal life	15%	33%	
In CHE 312 (midterm)	(N=43)	(N=16)	
Lack ability	0%	12%	
Don't work hard enough	60%	31%	.02*
Course too demanding	9%	31%	
Tests/grading unfair	9%	0%	
Problems in personal life	21%	25%	
In CHE 446	(N=43)	(N=18)	
Lack ability	2%	11%	
Don't work hard enough	70%	67%	.39
Course too demanding	16%	6%	
Tests/grading unfair	2%	0%	
Problems in personal life	9%	17%	
In remaining senior CHE courses	(N=51)	(N=16)	
Lack ability	4%	12%	
Don't work hard enough	69%	62%	.80
Course too demanding	14%	12%	
Tests/grading unfair	6%	6%	
Problems in personal life	8%	6%	

Table 10. Most likely reason if performance exceeds expectations.

	Men	Women	p
In CHE 205 (beginning)	(N=83)	(N=34)	
Real ability	31%	26%	
Work hard	63%	62%	.29
Help or support from someone else	5%	3%	
Course easier than expected	1%	6%	
Lucky	0%	3%	
In CHE 311 (midterm)	(N=47)	(N=15)	
Real ability	19%	13%	
Work hard	47%	33%	.36
Help or support from someone else	4%	20%	
Helped by group work	19%	27%	
Lucky	11%	7%	
In CHE 312 (midterm)	(N=44)	(N=16)	
Real ability	18%	6%	
Work hard	50%	38%	.27
Help or support from someone else	5%	19%	
Helped by group work	14%	12%	
Lucky	14%	25%	
In CHE 446	(N=43)	(N=18)	
Real ability	28%	22%	
Work hard	42%	44%	.04*
Help or support from someone else	0%	17%	
Helped by group work	16%	0%	
Lucky	14%	17%	
In remaining senior CHE courses	(N=51)	(N=16)	
Real ability	29%	12%	
Work hard	41%	44%	.14
Help or support from someone else	2%	19%	
Helped by group work	16%	19%	
Lucky	12%	6%	

C. Self -Assessment of Problem-Solving Abilities

Toward the end of their junior and senior years, the students were asked to rate their ability to solve basic engineering problems and more challenging problems requiring creativity. In the CHE 446 questionnaire they were also asked to assess their ability to solve routine and challenging problems they might encounter in industry following graduation, and in the senior questionnaire they were asked about their computer problem-solving ability. The men rated their basic problem-solving abilities significantly higher in every instance (Table 11). They also rated their abilities to solve particularly challenging problems, computer problems, and problems requiring creativity more highly, significantly so in the senior questionnaire and in the question about working in industry (Table 12).

Table 11. Self-rating of ability to solve basic problems.

	Men	Women	p
In CHE 312	(N=44)	(N=16)	
Excellent	30%	6%	
Good	57%	62%	.06*
Average	9%	31%	
Fair	5%	0%	
In CHE 446	(N=44)	(N=18)	
Excellent	39%	17%	
Good	50%	44%	.04*
Average	11%	33%	
Fair	0%	6%	
At end of senior year	(N=51)	(N= 16)	
Excellent	35%	19%	.06*
Good	59%	56%	
Average	6%	25%	
In industry	(N=44)	(N=18)	
Excellent	50%	33%	
Good	43%	33%	.04*
Average	5%	28%	
Fair	2%	6%	

Table 12. Self-rating of ability to solve challenging problems and computer problems

	Men	Women	p
Creative problems — CHE 312	(N=44)	(N=16)	
Excellent	9%	0%	
Good	48%	25%	
Average	27%	56%	.19
Fair	11%	12%	
Poor	5%	6%	
Creative problems — CHE 446	(N=43)	(N=18)	
Excellent	26%	6%	
Good	51%	56%	
Average	19%	33%	.24
Fair	2%	6%	
Poor	2%	0%	
Creative problems — end of senior year	(N=51)	(N=16)	
Excellent	22%	0%	
Good	63%	44%	
Average	14%	50%	.003*
Fair	2%	0%	
Poor	0%	6%	
Challenging problems in industry	(N=44)	(N=18)	
Excellent	30%	0%	
Good	48%	61%	.03*
Average	16%	28%	
Fair	7%	11%	
Computer problems at end of senior year	(N=51)	(N=16)	
Excellent	33%	6%	
Good	51%	56%	
Average	12%	31%	.07*
Fair	2%	6%	
Poor	2%	0%	

D. Reactions to Group Work

All homework in each of the experimental courses was done by teams of three or four students, with one assignment set handed in per group and rotating team leadership. Also, almost every lecture session involved some group work, taking up anywhere from 5 to 40 minutes of the 50-minute period. The homework groups remained together throughout the semester, while the group composition in class varied from one period to another.

Group work was viewed very positively by both men and women but more so by the women. Women gave higher ratings than men to both in-class group work and group homework in individual courses and retrospectively for the entire sequence. The female preference for group work was evidenced by the responses to a question posed in CHE 311, CHE 312, and CHE 446 asking whether the students would choose to work alone for the rest of the course if given the choice. High percentages of students of each sex responded that they would not choose to work alone (the numbers ranged from 86% to 100%), but the women's percentages were consistently higher.

In the second semester of their senior year, the men remaining in the experimental course sequence were twice as likely as women to feel that they did more than their fair share in their groups and the women were significantly more likely to feel that their contributions were undervalued or ignored by other group members. This feeling is similar to one expressed by female Radcliffe College students, who reported that too often their contributions in small mixed study groups were not valued and so they preferred to study by themselves.[26] When asked as seniors for their opinion of the principal benefit of group work, the men were much more likely to select explaining class material to others while the women were more than twice as likely to cite having the material explained to them. In free questionnaire comments, a number of women commented on their inability to be heard in mixed groups, and videotapes of group work sessions show a tendency of women to be relatively reserved in group interactions.

The attitudes toward cooperative learning summarized in the preceding two paragraphs (and reported quantitatively by Felder *et al.*[3]) are logically consistent with previously cited results. Women give higher ratings to group work than men because group work provides what they believe they need to succeed academically (external help, personal interactions). The men, however, may get more benefits from group work than they realize because they effectively learn the material by explaining it, which might account in part for their better performance in the experimental courses. Since the women take less active roles in the groups (whether by their own choice or not), the men are more likely to feel that they are doing more than their fair share of the work, a sentiment they express. The women's feeling that their contributions were undervalued in group work might have added to their lack of confidence in the experimental courses, accounting in part for the increasing gender difference in confidence levels as time went by.

VII. POST-GRADUATION PLANS AND PRIORITIES

In their junior and senior years the students were asked about their post-graduation plans. The men were much more inclined to pursue graduate study, with the difference becoming more pronounced as the students approached graduation. Toward the end of their fourth year, 54% of the men and only 18% of the women expressed intentions to go to graduate school, either immediately after graduation or after several years of working.

A relatively low tendency of women engineering graduates to go on to graduate school has been noted elsewhere, e.g. by Widnall.[6] One contributing factor might be a desire of some of the women graduates to start families shortly after graduation. Another possible factor is suggested by the observed gender differences in self-confidence at the end of four years in college. The women, less confident in their abilities to deal with challenging engineering problems, may be more reluctant to pursue a career track (research or university teaching) that would require advanced knowledge of the field and hence pursuit of a graduate degree. A third possibility is that the women might be less inclined to pursue academic careers due to the lack of female role models in their own university experience.[27]

VIII. DISCUSSION

Much of what we have just presented is both disturbing and easy to misinterpret. To be explicit, our data do not show—and we do not believe—that women are any less capable than men of being successful engineering students and outstanding engineers. What the results *do* suggest is that women in engineering school face obstacles that keep them from competing with their male counterparts on an equal footing. As the ensuing discussion will reveal, we also believe that observed male/female disparities in academic performance and confidence levels are attributable to a variety of social factors rather than intrinsic sexual differences and that measures can be taken to restore gender equity.

Some might question the degree to which our observations—based as they are on a relatively small sample of students in one department at one university—can be taken as representative of women engineering students as a group. We are convinced they can be, primarily because they are consistent with the results obtained in every comparable study we have encountered.[4,8,13,15–17,19–21,23,26] Rogers[25] summarizes the results of a number of studies, noting that *"Outside of women's intellectual development, the college experience has a negative effect on women resulting in loss of self-confidence, lowered career aspirations, and failure to develop personal characteristics associated with leadership and success in science and technology, such as independence and self-reliance."* Henes[29] concurs, observing *"Research has shown that male and female experiences in academic settings can be vastly different. Frequently these different experiences lead women to feel less confident, to contribute less to the class and to be perceived as less capable students."*

In short, we have no doubt that the lowering of expectations and confidence experienced by the women in our study is both real and representative of other engineering student populations. We may now speculate on its possible causes and potential cures.

A. What Accounts for the Observed Gender Differences?

The question to be addressed is, "Why did the women in the study—whose qualifications were arguably better than those of the men when they entered the chemical engineering curriculum—earn lower grades in chemical engineering courses and exhibit progressively lower confidence levels and expectations of themselves as they advanced through the curriculum?" One possible explanation involves inherent gender differences in certain abilities important in the solution of engineering problems; however, as discussed in the introduction, recent studies negate this explanation. The study data and observations in the literature suggest several more likely causes.

1. Uncertainties in students' minds about the suitability of women to be engineers.

A 1991 survey of 283 students at three universities asked the respondents to state their perceptions of barriers to women entering engineering.[5] Roughly 20% of the respondents cited beliefs that engineering is too demanding to combine with family responsibilities, men in engineering resent women colleagues, and most parents discourage their daughters from training for engineering. Almost 10% stated that women are afraid they will be considered unfeminine if they enter engineering. No significant gender differences in the responses were found.

Even though these beliefs were not strong enough to deter the women in this study from enrolling in engineering, they could still have contributed to undermining their confidence, especially when compounded with academic setbacks or the other problems listed below. The greater tendency of women to drop out of chemical engineering upon failing a course suggests the influence of these self-doubts.

2. Mismatches between characteristic instructional styles of engineering professors and characteristic learning styles of women students.

Many engineering courses stress theory (engineering science) over applications (engineering practice). This emphasis invariably places some students at a distinct disadvantage relative to others,[30] and in particular may work to the detriment of women, more of whom lack the hands-on experience that might clarify the abstract theoretical material.[31] Also, most engineering courses require individual work and grades are assigned on a competitive basis, whereas women tend to be more comfortable in an environment that stresses cooperation,[15] a tendency consistent with the strong enthusiasm for group work expressed by the women in this study.

The instructional approach in the experimental courses—particularly the emphasis on cooperative learning—had been intended to minimize the learning/teaching style mismatches that normally work against women in engineering. (The degree to which it did so will not be known until data for the comparison group have been analyzed.) However, as will be noted shortly, cooperative learning may be a two-edged sword for women students, creating some problems for them while resolving others.

3. Discrimination by faculty instructors and advisors.

Intentional faculty discrimination against the women in this study—if it occurred at all—is not likely to have affected their course grades directly. Examinations in chemical engineering courses consist almost entirely of quantitative problems with unique answers, grading is objective, and letter grades for the courses are based on examination and homework grades and not on subjective evaluations of such things as quality of expression or level of participation in class. Moreover, although differences between male and female performance were observed in the experimental chemical engineering courses, the anonymous student evaluations of the course instructor by both men and women were uniformly and consistently high, and although the women in the study had many opportunities in interviews and anonymous questionnaires to voice complaints about unfair treatment by the course instructor, no such complaints were ever received.

On the other hand, while the women in this study never registered complaints about discrimination by any of their chemical engineering course instructors, several reported hearing disparaging statements about women students from other engineering professors, which could certainly have contributed to a lowering of their self-confidence.

4. A tendency of women to be less active in cooperative learning groups.

Perhaps due to repeated devaluation of their contributions or to a learned tendency to defer to men in intellectual matters, the women played less active roles than the men in their groups. (This assertion is based on the women's own estimation and is supported by observation of videotaped group sessions.) Also, many more men than women felt that group work benefited them most by giving them opportunities to explain material to others, while more women felt that having material explained to them was the greatest benefit. All developmental learning theories agree that active involvement in learning is far more effective at promoting understanding than passive reception of information. The implication is that by taking more active roles in group sessions, the men were deriving greater benefits from cooperative learning.

5. Discounting by male classmates, including (and perhaps especially) in cooperative learning groups.

Widnall[6] cites studies showing that women in mixed groups are disadvantaged in several ways: they are interrupted more frequently, their contributions are often ignored or discounted, and they are uncomfortable with the argumentative style that many men characteristically adopt when points of contention arise. The data from this study are consistent with these observations. Women were far more likely than men to complain that their contributions in group work were undervalued. These feelings, which undoubtedly had some basis in reality, were bound to diminish the women's self-confidence.

6. Lack of female role models in engineering school.

Research has established the vital importance of role models for women in engineering.[27] The female students in this study would probably have benefited by being taught by women engineering professors but they only encountered one in a single course, and her effectiveness as a role model was diminished by her being in her first semester of teaching, co-teaching the course with a more experienced male colleague.

7. Different relative priorities attached by men and women to personal relationships and schoolwork.

As they progress through the curriculum, both men and women become involved in personal relationships that impose increasing time demands. It may be that the women tended to place a higher priority than the men on the relationships, making them less inclined to expend the time and energy required to earn top grades in their courses.

B. What Support Should Be Provided for Women Engineering Students?

Whatever the reasons for the observed gender differences, it is clear that women in engineering school are operating at a disadvantage relative to men and that American industry and universities are losing valuable talent as a consequence. Henes[29] suggests several measures to restore gender equity in engineering classes, such as being careful not to use gender-sensitive material and language, avoiding routine placement of women in stereotypical female ("secretarial") roles in group work, and seeking equal involvement of all students, recognizing that women may tend to be less assertive than men in volunteering responses or asking questions in class. The observations summarized in this paper suggest that the following additional measures could help to put male and female engineering students on an equal footing.

1. Provide engineering students with female role models and mentors.

The need for female role models for women students in science and engineering has been widely noted,[6,27,31] as has the importance of out-of-class student-faculty interactions in promoting academic success and building self-esteem.[23,32] Perhaps the most effective way to help women engineering students would therefore be to add more women to engineering faculties.

This objective is not easily realized, however, especially in the near term. The relatively small number of women currently in the engineering graduate school pipeline is far less than the number needed to mentor the women now enrolled as engineering undergraduates, let alone the number who will be enrolled if current recruitment and retention programs succeed. Moreover, women professors are rightfully expected to meet the same performance standards as their male counterparts. It is unreasonable to expect them to seek and secure research funding, perform the research, publish and present papers, and develop and teach courses to the same extent as the men and simultaneously to spend the time that serious mentoring requires. Until the number of women entering the professoriate increases substantially and the university infrastructure comes to view mentorship as a valid and vital professorial function, other mechanisms to support women students will be needed.

One possible mechanism is peer mentoring. Female graduate students and upper-class undergraduates could be effective mentors to first-and second-year women, and could reach many more students in a meaningful way than could possibly be reached by the few available women professors.

2. Strengthen organizations that can provide career guidance and emotional support to women students, such as student chapters of the Society of Women Engineers, and encourage participation in these organizations.

Besides serving as valuable support groups, such organizations provide a natural forum for successful women engineers to return to campus and provide a realistic and positive picture of engineering as a career for women.

3. Use cooperative learning in engineering courses, structured to provide equal benefits to men and women.

By their own assessment, the women in this study were helped considerably by working in groups, and other studies have also shown that women respond positively to a classroom environment based on cooperation rather than competition; however, the tendency of some women to take less active roles than men in groups and that of some men to devalue women's contributions can work against the women. When mixed groups are formed, the need to elicit and value contributions from *every* group member should be stressed, and the groups should regularly be required to assess their success in this regard.

As a rule, cooperative groups in which men outnumber women should be avoided, and it might also be worthwhile to experiment with groups containing only women. Studies have shown that students at women's colleges do not experience the same loss of self-esteem as women at coeducational institutions,[33] suggesting that female study groups might provide the benefits of cooperative learning to women while avoiding the potential drawbacks of this approach.

4. Educate professors and academic advisors to the problems and needs of women students.

Beal and Noel[34] cite research showing that student retention can be increased through improved academic advising. Unfortunately, most professors receive the same level of training for advising that they do for teaching—that is, none. All faculty members should be made aware of the difficulties faced by women engineering students and of the resources on campus—support groups, mentorship programs, trained counselors, etc.—available to help the women cope with and overcome these difficulties.

IX. SUMMARY AND CONCLUSIONS

The backgrounds and pre-engineering academic credentials of the women in this study marked them as more likely to succeed than the men. Their parents were on average more highly educated and had received more training in science or technology, they scored equally well or better than the men on pre-college admission tests, and *Learning and Study Strategies Inventory* results indicated that they were more highly motivated to study and made better use of study aids. Nevertheless, the women did no better than the men throughout college except in non-technical courses. Men and women did equally well in overall GPA and pre-engineering mathematics and science courses, and the men generally outperformed the women in chemical engineering courses, both in average grade and in the percentages receiving A's.

Of the students who had intended to major in chemical engineering when they began the first course, the percentage of women who dropped out for any reason after the sophomore year was twice the percentage of men dropping out. The percentages dropping out by the end of the senior year were closer, with relatively more women transferring into other curricula and more men dropping out of school or being suspended. Throughout the period of the study, men who failed a chemical engineering course were more likely than women to repeat the course and remain in the curriculum, while women who failed a course were more likely to switch out of chemical engineering. Of those who persisted in the curriculum, men were significantly more inclined than women to express an intention of going to graduate school.

The women in the study entered the engineering curriculum with greater anxiety and lower confidence in their preparation than did the men. They began the first course with higher expectations of themselves, but by the midpoint of the first chemical engineering course their expectations were lower and the disparity persisted throughout the curriculum. As they proceeded through the curriculum, the men consistently expressed higher self-assessments of their abilities to solve basic engineering problems, problems that required creativity, and computer problems. The gender difference in self-assessed ability to solve problems creatively became more pronounced as the students approached graduation. The women were more likely than the men to attribute poor performance to their own lack of ability and the men were more likely to attribute it to a lack of hard work or being treated unfairly. Conversely, the men were more likely than the women to attribute success to their ability and the women more likely to attribute it to outside help.

Cooperative (team-based) learning was a major component of the experimental course sequence and was viewed positively by both men and women but more so by the women; however, the women were also significantly more likely to feel that their contributions were undervalued by other group members. When asked what they perceived to be the greatest benefit of group work, the men were much more likely to say they benefited from explaining the material to others while the women were more likely to cite having the material explained to them.

We can only speculate on the causes of the observed gender differences in performance and attitudes. Some undoubtedly have to do with attitudes and prejudices acquired prior to college (e.g. negative beliefs held by both women and men about women's suitability for technical subjects); some involve differences in priorities and goals (e.g. different relative priorities placed by men and women on personal relationships and classwork); others involve a shortage of female role models and mentors in engineering; and still others relate to the instructional methods and the attitudes of professors, advisors, and classmates (e.g. an emphasis on competition in engineering courses and anti-female bias on the part of some male faculty members and/or students). Suggestions for restoring gender equity include providing women engineering students with female faculty and student role models and mentors; strengthening support organizations such as the Society of Women Engineers and encouraging participation in them; using cooperative learning, structured to provide equal benefits to men and women; and educating professors and academic advisors about the problems and needs of women students.

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